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SIMULATION OF WINDDRIVEN MIXING OF SEA OUTFALL PLUMES

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1. INTRODUCTION

From an environmental point of view is the length of a sea outfall the most important parameter in the design stage. Bathing water quality on the adjecent shore expressed as a statistical requirement to the concentration of the indicator bacteria E.coli (Escherichia coli) will in many cases be the factor, which determine the length of the pipeline.

To predict the E.coli concentration along the shore in the neighbourhood of an outfall we need considerations of

1. The soure-strength of E.coli
2. Die-off of E.coli
3. Dilution of the sewage plume

This paper describes a numerical model, which on the basis of Monte Carlo simulation can calculate a large number of independent instantaneous pictures of the E.coli-distribution, from which a statistical analysis can be performed.

2. PHYSICAL CONSIDERATIONS

From field measurements along Danish coasts it is known that transport and dilution of sewage plumes most often are controlled by

1. Tidal and net-current parallel to the shoreline
2. Winddriven surface currents and windgenerated turbulence

This is of course not a general experience, exceptions can be seen. In many other coastal engineering problems the bottom shear and the bottom generated turbulence are important factors, but not often in respect to sea outfall plumes. The major reason is that we are most interested in the high concentration of sewage, which occurs when the weather is calm and the sea is more or less stratified near the bottom.

To describe the sewage plume under the above mentioned conditions, a 3-dimensional unsteady model is needed. To model a large number of current/wind situations we demand the highest degree of simplicity and fastness in the numerical simulation.

3. MONTE CARLO MODEL

The model used, is a particle- or stochastic model, where the solution of the 3-dimensional diffusions/advections-equation is approximated by tracking a large number of particles. The advectiv motions of the individual particle is the effect of the actual current, and the diffusion is simulated by giving the particles stochastic jumps controlled by random numbers. The position of a particle in the next time-step is

$$x_i^{n+1} = x_i^n + U_i \Delta t + \sqrt{2D_i \cdot \Delta t} \ \text{random}\ (0,1)$$

where

x_i^n cartesian coordinate $i = (1,2,3)$

U_i advectiv velocity

Δt time step

D_i diffusion coefficient

Random (0,1) random number from a normal-distribution with average equal to zero and standard deviation 1

The boundary conditions are the sea surface and the sea bottom. Numerically are these treated by reflecting particles, which cross the boundary.

The 3-dimensional flow-field was assumed to be a superposition of a non-turbulent tidal current and a turbulent wind-driven surface current. The wind drift profile was logarithmic distributed and followed the winddirection.

The diffusion coefficients were according to Reynold's analogy assumed to be equal to the eddy viscosity and taken from the theory of boundary layer. Field experiments (Churchill, J.H., Csanady, G.T. (1982)) confirm these assumptions to be valid in the top 2-5 m of the sea.

The bacteriological mortality was taken into account by assuming an exponential decay.

4. RESULTS

As mentioned in the introduction it is the purpose of this method to establish a large number of instantaneous pictures of the E.coli-distribution in order to carry out a statistical analysis. Fig. No. 4 shows an example of an instantaneous picture of a situation, which seems to be critical for the bathing water. This situation occurs shortly after the turning of the tidal current under the influence of an on-shore directed wind.

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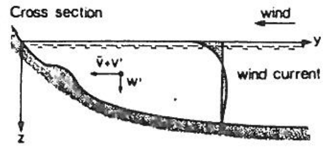

Fig. 3. Schematic outline of random walk model, cross-section.

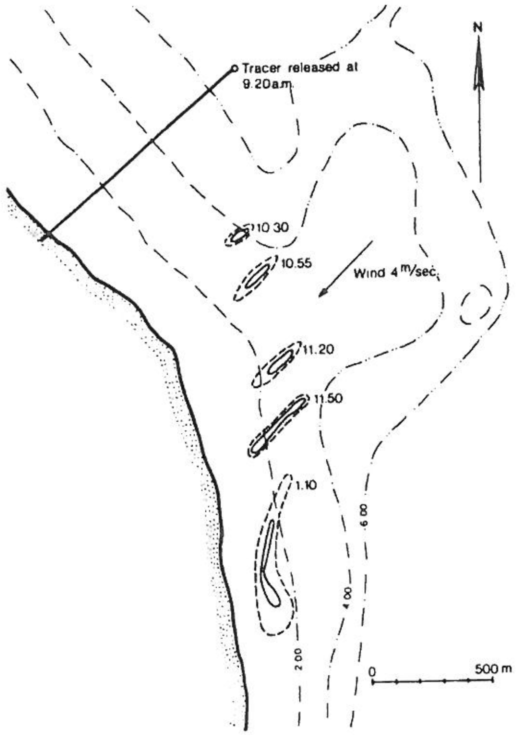

Fig. 1. Tracer Experiment in the Limefjord North of Nykøbing Mors, Denmark, 05.08.1976. Wind from NE.

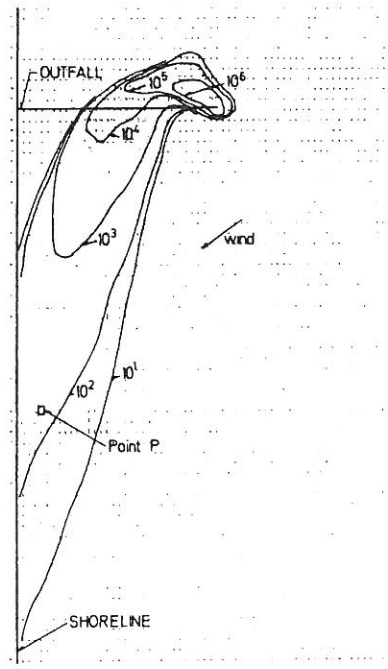

Fig. 4. Instantaneous picture of surface concentration of E.coli.

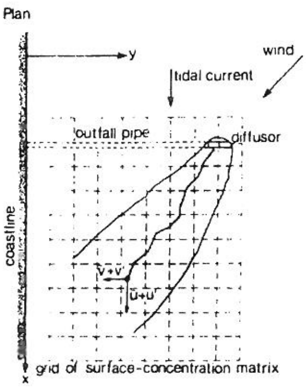

Fig. 2. Schematic outline of random walk model, plan.

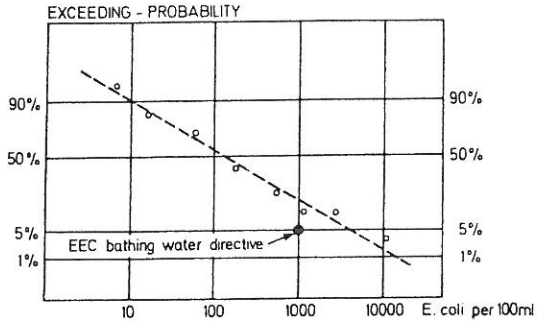

Fig. 5. Computated bathing water statistic for point P (see Fig. 4.).